E3A: Ground Source Heat Pumps

Robbin Garber-Slaght, Vanessa Stevens, Molly Retting, and Art Nash; Milton Geiger editor E3A Program

Steps in the Heat Pumps Series

B-1284 | E3A-GSHP.0

Ground source heat pump system
Photo by Chris Sullivan NREL 17555 http://images.nrel.gov/viewphoto.php?imageId=6310746

OVERVIEW

Energy from the Earth

Ground source heat pumps (GSHPs), also called geothermal heat pumps and geo-exchange, provide space heating and cooling for buildings, including residences, businesses, or barns. During winter, GSHPs use electricity to operate pumps that circulate a fluid through piping to transfer heat from the ground or body of water to a structure's interior. GSHPs can be reversed to provide cooling by transferring heat from a building into the ground or body of water. GSHPs can also heat domestic or agricultural, commercial, or industrial process water.

GSHPs are considered both an energy efficiency improvement and arenewable energy system. These systems use electricity, potentially from non-renewable sources, for heating or cooling, but GSHPs also collect solar energy and geothermal energy stored in the ground. Buildings throughout the United States use GSHPs, from cooling dominated (i.e., airconditioning) loads of Nevada to heating dominated loads of Alaska.

Efficient Space Conditioning

Unlike space heaters or electric baseboard, which convert electricity directly into heat, GSHPs use electricity to collect and "step up" (i.e., concentrate) the natural heat of the ground. The heat is then transferred to a building. In the cooling mode, heat is

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transferred from the building to the ground. GSHPs are more efficient than other types of heating appliances, often gathering 2-6 units of usable heating/cooling from 1 unit of electricity. The efficiency factor, called the Coefficient of Performance (CoP), is possible because GSHPs, like all heat pumps, transfer heat (see Figure 1).

The initial cost of GHSPs is higher than traditional heating and cooling systems, but reduced operating costs and environmental impacts can justify the cost for building owners. The relatively high initial investment cost of GSHPs is primarily for the ground loops, which require extensive excavation or drilling work. Also, when paired with low-carbon electricity sources, such as on-site photovoltaics or utility-provided wind energy, GSHPs can reduce emissions associated with non-renewable energy consumption.

Additional Resources

The Department of Energy's Energy Savers website provides text and video information on geothermal heat pumps: www.energy.gov/energysaver/articles/geothermal-heat-pumps

The International Ground Source Heat Pump Association, headquartered at Oklahoma State University, promotes the use of GSHPs through education for building owners and installers: www.igshpa.okstate.edu The Geo-Heat Center at the Oregon Institute of Technology makes research findings on GSHPs available on its website: www.oit.edu

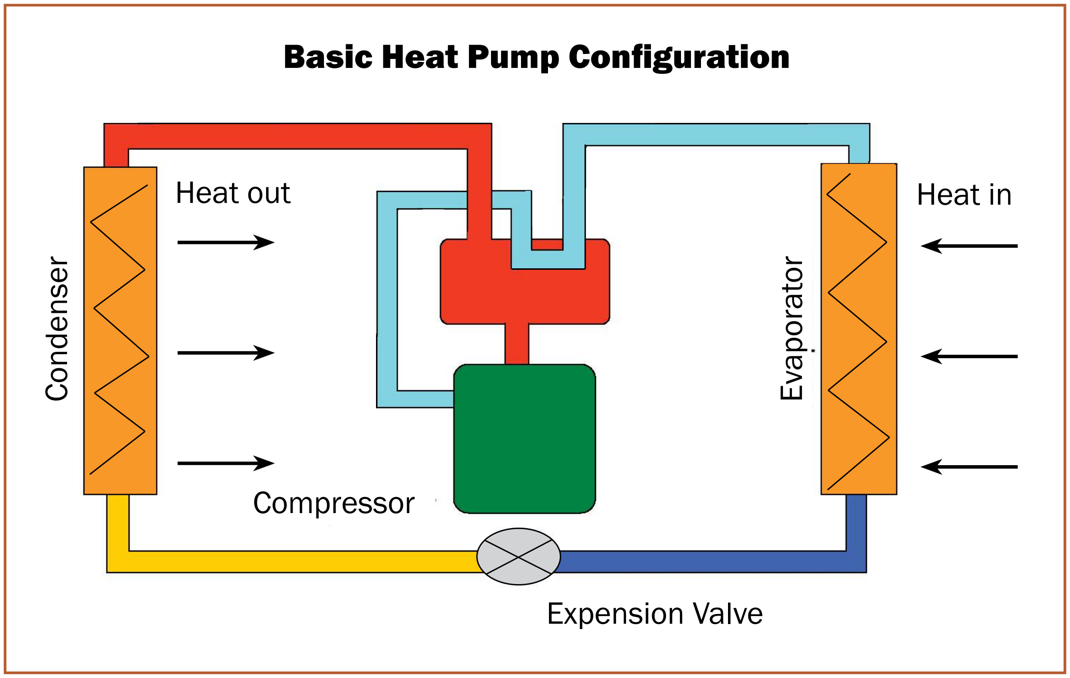

Figure 1: Basic Heat Pump Configuration (Source: Alaska Center for Energy and Power)

Notes

STEP 1

E^{3}A: Ground Source Heat Pumps

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Steps in the Heat Pump Series

GSHPs provide space heating and cooling by transferring energy between the ground or body of water and a building. They are very different from combustion appliances, such as furnaces, stoves, and boilers, which create heat by burning natural gas, propane, fuel oil, or wood. In heating mode, the heat pump removes heat from the ground or body of water through a circulating fluid and then transferring heat to a building. In cooling mode, GSHPs "dump" heat from the building's interior into the ground, much like a refrigerator transferring heat from the inside the icebox to the outside through fluids and coils. In both cases, GSHPs use electricity to operate a compressor and pump to facilitate this heat transfer. In short, GSHPs rely on both electricity and "free" energy of the earth.

A Renewable Energy Technology?

Heat pumps are considered a partially renewable energy technology. The energy available to GSHPS is a combination of heat from the sun and earth (geothermal. The energy harvested from the ground in the winter is replaced by the sun in the summer, thus the resource is renewable. Using the system for cooling also transfers heat back to the ground in the summer. The electricity used to operate the compressor and pump may not be from renewable sources unless renewable energy is purchased from a utility (i.e., renewable energy credits) or produced on-site from small wind or solar. Like other electric heating systems, an existing GSHP may become "more renewable" as utilities integrate more renewable energy into their fuel mixes.

Heat Pump Components

GSHPs consist of three main parts:

- Ground loop heat exchanger embedded in the ground or a water source,
- Heat pump/compressor, appliance inside a home, and
- Distribution system that moves heat throughout a building.

The ground loop component is comprised of tubing that passes through the heat source/sink. (If used for heating, then the heat source is the ground; if used for cooling, the heat source is the building and the ground is a heat sink). The loops can be buried in the ground vertically or horizontally in various configurations. Loops can also be placed in a water body. Heat is transferred to or from the ground/water to a fluid.

Ground-coupled heat exchanger of a heat pump: loop field for a 12-ton system.
Photo by Mark Johnson (Marktj at English Wikipedia) (Own work) [Public domain], via Wikimedia Commons

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Polyethylene pipe
Photo by John Barlean, NREL 07292
http://images.nrel.gov/viewphoto.php?imageId=6317366

Both closed loop and open loop designs can be used. The design of a loop field is fully explained in Step 3.

The heat pump and compressor move heat from/to the ground and "step it up" to a temperature usable for space heating through a refrigeration cycle (illustrated in Figure 2). In the cooling mode, the same refrigeration cycle is reversed to concentrate heat energy from the building interior, allowing energy transfer to the ground. Alternately, in some cooling systems, the refrigeration loop is bypassed, and the fluid transfers heat directly to the ground. The distribution system moves heat into or out of a building. GSHPs are compatible with many standard distribution systems, including some hydronic (e.g., in-floor heating) and forced air systems. In heating-dominated climates, low-temperature distribution systems are preferred.

Refrigeration Cycle

The refrigeration cycle used in a GSHP system in a heat pump is similar to a refrigerator. Figure 2 shows the operational flow of a heat pump system working in the heating mode. The ground loop fluid (in blue) passes heat to the refrigerant fluid (in tan) cycling within the heat pump, which then boils at low temperatures and turns into a gas. This vapor is compressed (in red), further raising the temperature. The heat is then passed to the building's distribution system. The cycle is completed when the refrigerant is condensed. While a GSHP system requires electricity to run the pumps/compressor, the primary source

Refrigeration Cycle

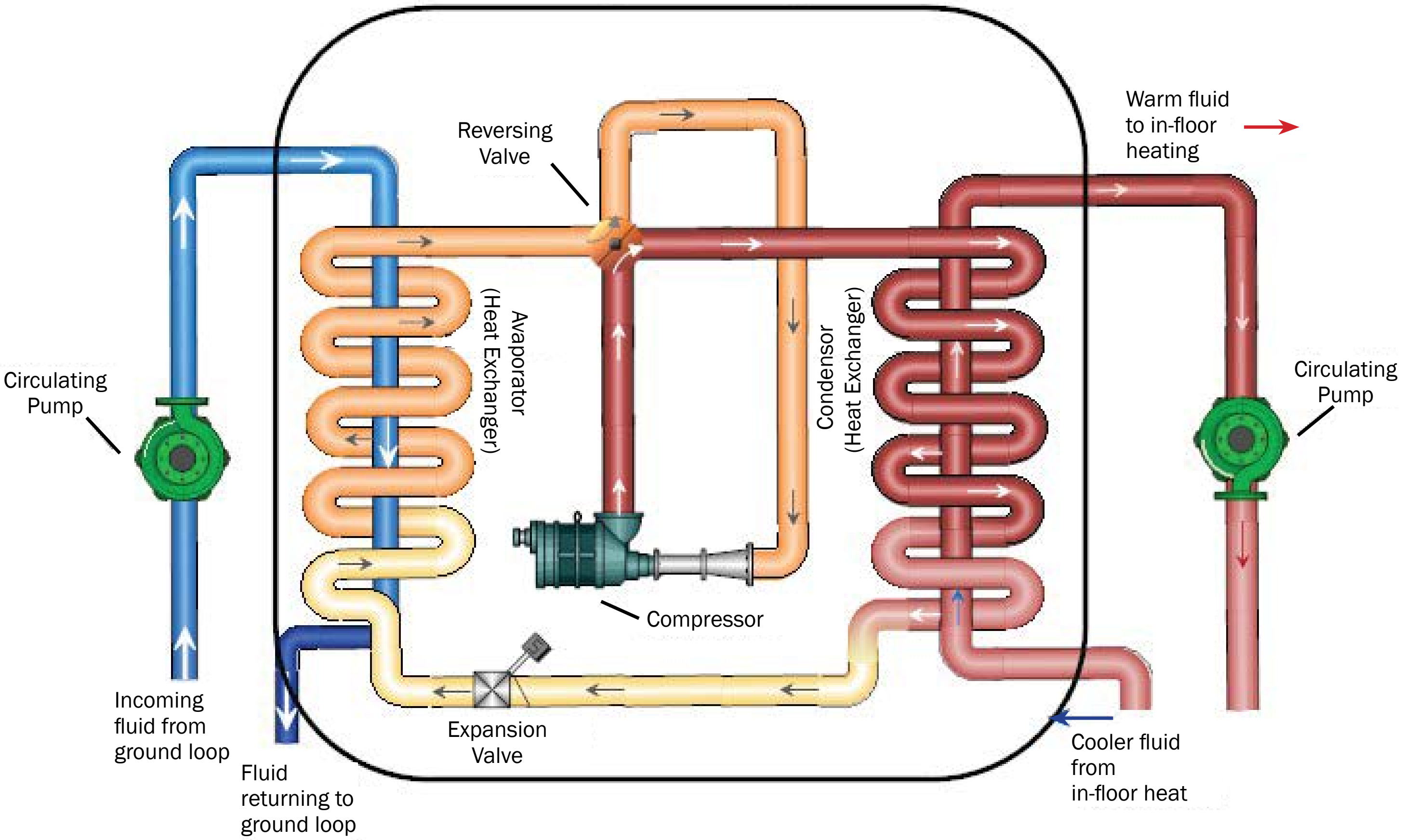

Figure 2: The Refrigeration Cycle courtesy of the Alaska Cold Climate Housing Research Center

of heat is the energy gathered from the ground. In cooling mode, this cycle operates in reverse, collecting heat from the interior of the building and sending it to the ground loop for dispersal.

Efficiency

GSHP efficiency in space heating is often measured by calculating the Coefficient of Performance (COP). The COP is simply a ratio of the amount of heat delivered to a building by the heat pump as compared to the electrical energy that the heat pump uses to run the refrigeration loop.A COP of three means that for every one unit of electrical energy used by pumps and compressors, the system delivers three units of heat energy to a building. The COP of a heat pump is affected by the temperature of the earth/water soil surrounding the ground loop and by the temperature required in the distribution system. Higher ground temperatures and lower distribution temperatures reduce the amount of "lift" required from the heat pump, allowing systems to operate more efficiently with less electricity. When in the cooling mode, the performance is measured by the Energy Efficiency Ratio (EER). The EER is the ratio of the amount of cooling provided compared with the electricity required to operate the entire system. As with the COP, a higher EER value indicates greater efficiency. Efficiencies measures are also reported by seasonal values – Seasonal COP (SCOP) and seasonal EER (SEER). The seasonal measures consider efficiency impacts due to ground temperature changes, as well as efficiency losses due to the pump and compressors cycling. Seasonal measures assume there is no exposure of pipes to the outside weather, but rather a direct connection from underground to the building. Overall, seasonal values are a more accurate representation of the efficiency of the heat pump operating throughout the year in a building or home.

Resources

Visit the Department of Energy's Energy Saver website, www.energy.gov/energysaver/articles/geothermal-heat-pumps for videos on how GSHPs provide space conditioning.

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STEP 2

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E^{3}A: Ground Source Heat Pumps

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As the number GSHP installations have increased throughout the United States, so have the options for installing a ground loop. The options are especially bountiful in many rural settings, where ample space allows for tailoring installations to local geology, ground cover, and required heating/cooling production. There are three general types of ground loops: closed, open, and hybrid.

Closed loop options

Traditional closed ground loop systems consist of installing pipe, usually made from high density polyethylene, into horizontal trenches, vertical wells, or directionally drilled boreholes (see Figure 4). In a horizontal trench configuration, lines or loops of pipe are placed in trenches excavated near the building. The depth of trenches varies based on soil type, water table, frost depth, and solar radiation incident on the ground, but the pipe is typically buried between 4-12 feet underground. Horizontal trenches involve considerable excavation work, as a medium-sized residence will often require a ground loop configuration of at least four trenches, with each being at least 100 feet long. This type of layout is often constrained by lack of space for trenches and maneuvering room for excavation equipment.

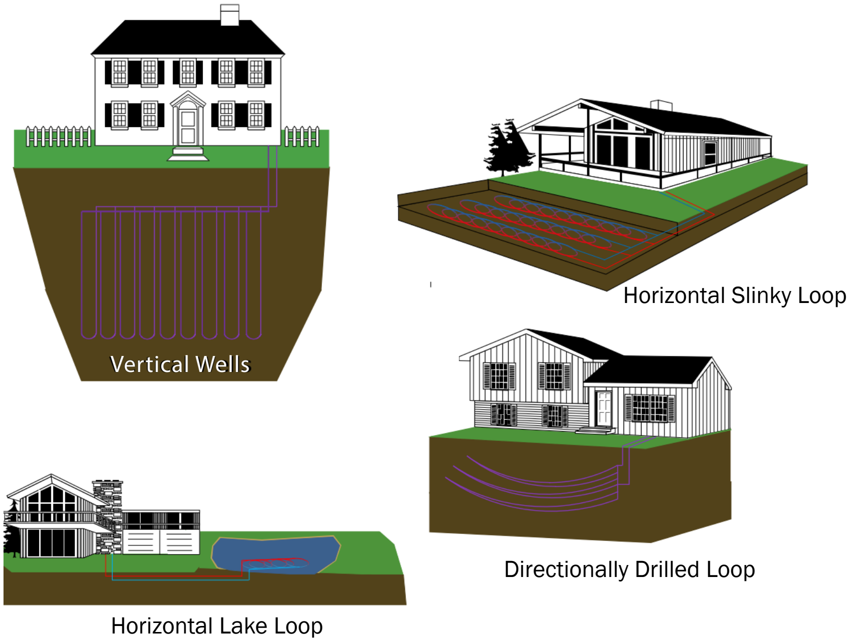

Figure 4: Ground loop configurations
Source: http://www.cchrc.org/sites/default/files/docs/Ground%20Source%20Heat%20Pumps%20in%20Interior%20Alaska.pdf

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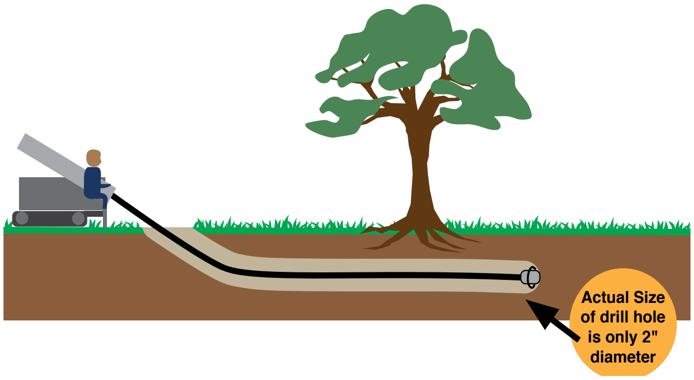
When horizontal trenches are either infeasible (e.g., inadequate space) or not preferred (e.g., mature landscaping), vertical wells can be drilled. Boreholes are typically drilled to around 100 to 400 feet deep (depending on local geologic conditions). With a u-bend at the bottom of the hole, fluid is circulated in the pipe from the surface to the bottom and back to the surface, transferring heat energy between the fluid and the earth. The surface area required is considerably less than for a horizontal ground loop, and there is more flexibility with the surface covering. For instance, vertical wells can be drilled beneath an existing parking lot or mature landscaping.Another closed ground loop option involves placing the loop coils in a body of water, such as a pond, lake, or even an ocean. Water provides an excellent heat conduction medium for the piping, but this option presupposes a nearby body of water that does not freeze solid in the winter. In the rare conditions where available, a loop in water is often the most economical design option. The most recent innovation in closed ground loop designs uses horizontal directional drilling. This configuration layout consists of straight horizontal pipes installed by using a directional drilling machine rather than excavation equipment. There is minimal disturbance to the surface landscaping. To install a directionally drilled ground loop, header and footer trenches are dug to connect the pipes, and then a drill is used to install underground pipes in a shallow arc between the two trenches.

Directional drilling
Photo by Ditch Witch. Licensed under CC 2.0 via Wikimedia Commons - https://commons.wikimedia.org/wiki/File:Ditchwitch_jt4020_mach1.jpg



Pond Loop Being Sunk
Photo by Mark Johnson (Marktj at English Wikipedia) - Own work. Licensed under Public Domain via Commons - https://commons.wikimedia.org/wiki/File:Pond_Loop_Being_Sunk.jpg#/media/File:Pond_Loop_Being_Sunk.jpg

Open-loop systems pull water directly from a well or surface water, circulates through the heat pump, and then discharges it. Open-loop systems can often be less expensive to install than closed-loop systems, as they require less pipe and excavation; however, local, state, and federal regulations regarding groundwater discharge must be met. Water quality (e.g., hardness and mineral content), seasonal water temperature, and variations in the flow must also be considered.

Hybrid options

A hybrid GSHP system combines the ground loop with another combines the ground loop with another technology for space conditioning. For heating-dominated systems, the ground loop can be combined with solar thermal collectors, which can provide direct space heating or can recharge the soil around the ground loop with heat. In a cooling-dominated climate, the ground loop might be combined with a cooling tower or cooling pond for additional heat rejection. A GSHP could also be coupled with a conventional system, such as electric resistance heat or boilers, to provide space heating.

Heat Delivery Systems

There are several considerations when looking into a GSHP system. First, consider the heating/cooling delivery mechanism in the building. Is warm air blown in through ducts, or does it come from hot water? The mechanism of delivery is important because a GSHP is most efficient at lower delivery temperatures. For example, forced air and in-floor radiant heating are typically compatible with a GSHP, as they require fluid temperatures under 110 °F degrees; however, hot water baseboard systems require temperatures between 120°F to 180°F and are thus generally not compatible with a GSHP.

Ground Loop Considerations

The optimal type of ground loop system is site dependent. Open loop systems require a well or a large water body to extract and discharge fluid. Horizontal loop systems require a large plot of open land to dig trenches and place the loops. A directionally drilled loop needs less open space but still requires a fairly large yard/field/parking lot. If space is limited, vertical wells can have an acceptably small footprint and can even be installed under a driveway. The geologic characteristics, land area, tree cover, and water table depth affect what type of drill can be used and how well heat is conducted between the ground and loops.

Another consideration is how the ground loop will be recharged with heat. In heating-dominated climates, there is potential to extract more heat energy from the ground in winter than is returned in summer, thereby depleting the heat source. Using a GSHP for cooling in summer will return some heat to the ground, but the rejected heat may not be enough to fully "recharge" the heat source. The summer sun also helps recharge the ground, so a horizontal loop should ideally be in a location with limited shading. Additionally, in winter, snow pack on top of a ground loop will reduce heat loss, as snow helps insulate the ground from cold winter air temperatures.

Geothermal drilling for residential heating
Photo by Olli Niemitalo - Own work. Licensed under CC0 via Commons https://commons.wikimedia.org/wiki/File:Geothermal_drilling_for_residential_heating.jpg

Depending on the type of ground loop installed, permits may be required from municipalities, counties, or states. In general, closed loop systems do not require significant permitting, although a loop field placed in a body of water often requires a permit; additionally, an open loop system can require state and federal permits. Local installers should be well-versed in permitting requirements.

Resources

Montana Department of Environmental Quality. (2008). "Geothermal/Ground Source Heat Pumps." Fact Sheet SWP-108. Retrieved Nov. 24, 2014, from http://deq.mt.gov/wqinfo/swp/PDFs/Factsheet_108_Geothermal_GSHP.pdf

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STEP 3

E3A: Ground Source Heat Pumps

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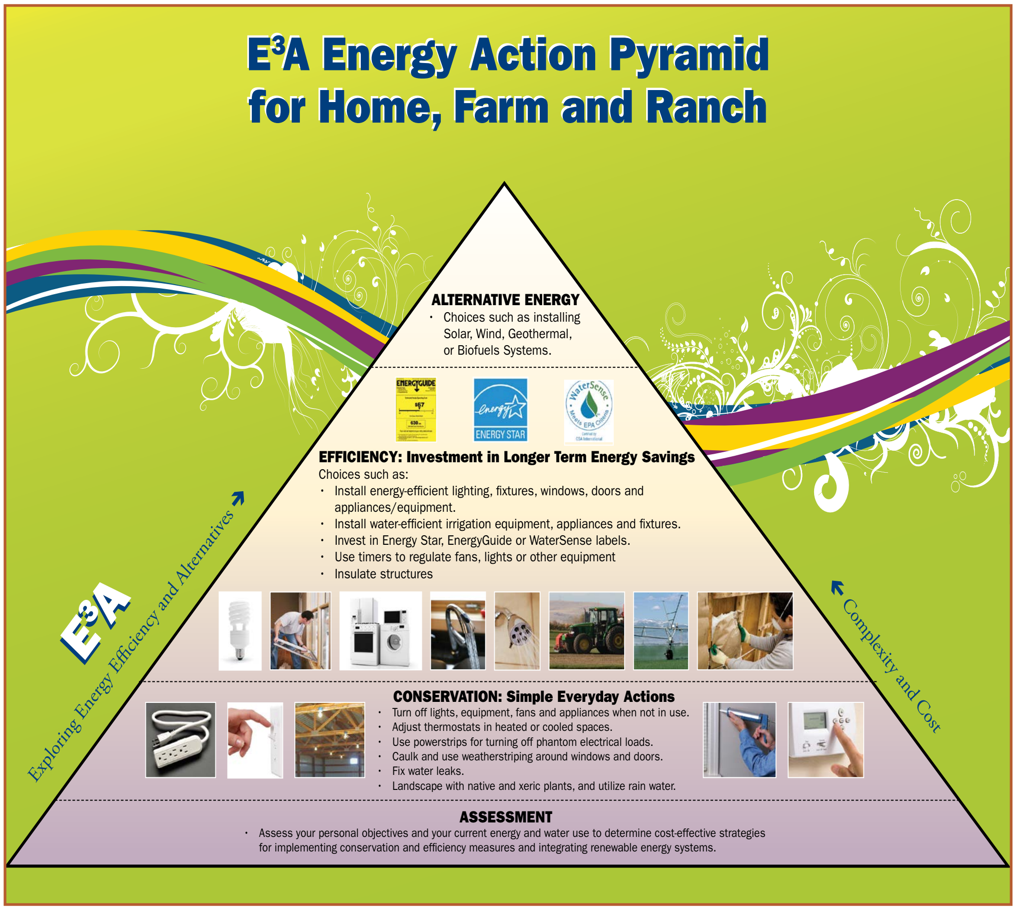
Although the application of GSHPs is exciting to many, energy conservation and efficiency measures should always be considered first. Why? Primarily because the size of a heating/cooling system is based on the amount of heating/cooling a building needs, often set by the requirements for the coldest day of the year. Simply, in a heating-dominated climate, the less heat needed, the smaller the investment in loops/tubing and the more affordable the system will be to operate. Thus, energy conservation and efficiency improvements will not only reduce the upfront cost of the heating system but also provide long-term energy savings. Conversely, the more heat needed, the larger the investment in loops/tubing and the more expensive the sytem will be to operate.

A qualified installer will assess the space heating and cooling demand (as well as domestic hot water if desired) before recommending a GSHP layout. The size and cost of the system depend on the heating and possibly domestic hot water demand, so make energy efficiency improvements (see suggestions below) *before* contacting a contractor for a GSHP design.



E3A Energy Action Pyramid for Home, Farm and Ranch

ALTERNATIVE ENERGY

- Choices such as installing Solar, Wind, Geothermal, or Biofuels Systems.

EFFICIENCY: Investment in Longer Term Energy Savings

Choices such as:

- Install energy-efficient lighting, fixtures, windows, doors and appliances/equipment.
- Install water-efficient irrigation equipment, appliances and fixtures.
- Invest in Energy Star, EnergyGuide or WaterSense labels.
- Use timers to regulate fans, lights or other equipment
- Insulate structures

CONSERVATION: Simple Everyday Actions

- Turn off lights, equipment, fans and appliances when not in use.
- Adjust thermostats in heated or cooled spaces.
- Use powerstrips for turning off phantom electrical loads.
- Caulk and use weatherstriping around windows and doors.
- Fix water leaks.
- Landscape with native and xeric plants, and utilize rain water.

ASSESSMENT

- Assess your personal objectives and your current energy and water use to determine cost-effective strategies for implementing conservation and efficiency measures and integrating renewable energy systems.

Source: http://mysare.sare.org/mySARE/assocfiles/935152Pyramid.pdf

Steps in the Heat Pump Series

1. How Ground Source Heat Pumps Works
2. Ground loop options
3. **Conservation and Efficiency**
4. Sizing
5. Choosing an installer
6. Economics
7. Operation and Maintenance
8. Other Geothermal and Heat Pump Options

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Operations and Maintenance

Regardless of the type of heating or cooling system, regular maintenance will keep the system operating at peak efficiency. Most heating systems should get a yearly check up to ensure they are operating safely and correctly. Some tasks can be performed by system owners, such as changing filters in a forced air distribution system. In general, a GSHP requires less maintenance than a combustion appliance, but a regular professional tune-up is still important to maximize system efficiency and reliability.

GSHPs typically are installed with advanced controls, particularly technology-specific programmable thermostats, which reduce consumption by allowing the temperature to be set by the hour, day, and month. For instance, the thermostat can be adjusted for nighttime temperatures. Also, control displays usually indicate if there is a problem with the heating system as well, allowing for prompt repair.

Efficiency tips for space heat in buildings: Invest in long-term energy savings

If the building utilizing a GSHPs is poorly air-sealed (i.e., leaky) or does not have much insulation, these problems should be addressed before installing a new system. Hire a professional to conduct an energy audit to accurately determine the quality of the building envelopes. An audit measures the insulation and air tightness of a building while finding the weak spots in the building envelope. Some weatherization tasks can be completed in just a weekend – like caulking leaky windows or weather-stripping doors. Other tasks, such as retrofitting walls or adding insulation in the attic, may need to be addressed by a professional. These repairs may allow buying smaller, less expensive heating (as well as distribution) systems.

While some use a forced air system to deliver heated and cooled air, other buildings use hydronic distribution systems such as a radiant floor or hot water baseboard. Either way, the efficiency of the working system should be evaluated. For forced air systems, a pressure test can identify leaks in the ductwork and thus avoid wasted energy. In hydronic systems, there may be areas where pipes can be insulated that are carrying heated water/glycol solution that pass through unconditioned spaces. Distribution systems can also be "zoned," which involves dividing the building into sections so the heating system can maintain different temperatures in different areas of the building. Each zone has a thermostat and distribution loop, and a central heating device controls heat delivery to different zones. Guest rooms, basements, pole barns, and workshops are great candidates for zoning because they do not need as much conditioning when not in use. Also, sunny rooms or rooms with a wood stove can be zoned separately so the individual thermostat can be turned down.

Resources

The Energy Star website has a Home Advisor tool that will help increase comfort and efficiency in a home by analyzing a home's systems, including space conditioning: https://www.energystar.gov/campaign/home?c=home_improvement.hm_improvement_index The Department of Energy also has a website with information on all aspects of home energy efficiency: http://www.energy.gov/energysaver/energy-saver

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STEP 4

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Steps in the Heat Pump Series

GSHP Loop field entering a building
Photo: Robert R. Jones ,NREL 07094 http://images.nrel.gov/viewphoto.php?imageId=6313766

Heat Pump Sizing

GSHPs are typically sized based on "tons" of cooling. A ton of cooling is equal to extracting 12,000 BTU/hr of heat from a space. For example, a 5-ton heat pump will be capable of extracting 60,000 BTU/hr of heat from a space. That doesn't necessarily mean it supplies 60,000 BTU/hr of heat to a space, though. The heat delivered to the space is dependent on the temperature of the fluid from the ground loop – the higher the temperature, the more heat that can be delivered. Thus, a 5-ton GSHP might deliver 53,000 BTU/hr or 65,000 BTU/hr depending on the temperature of the incoming fluid. Understanding the local ground temperature is vital to ensuring the GSHP can deliver adequate heating and cooling to a structure. In heating-dominated climates, GSHPs are typically sized based on the amount of space heating needed for the building. In cooling-dominated areas, the cooling needs would dictate sizing.

Rightsizing considerations

A heating system should be sized to meet the heating demand of a building on the coldest day of the year (or, the cooling demand on the hottest day if sized based on cooling). During the coldest day, the GSHP should be running continuously. An oversized GSHP will increase initial costs and operate less efficiently, as the unit will

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cycle on and off for much of the heating season. A properly sized heating appliance will have long runs with steady state efficiency. As described in step 5, if planning to make energy efficiency improvements to a building envelope (for instance, adding insulation in an attic, replacing windows, or sealing air leaks), these should be completed before buying the heat pump to reduce the building's heating load, while allowing the purchase of a smaller, less-expensive heat pump.

Determining your space heating demand

The heating demand of a building is a complex calculation that takes into account the size of the building, the amount of insulation, the number of windows and doors, and the local environment. There are several ways to calculate this heating demand, but these complex calculations are typically performed using computer models. Energy-raters or heat pump installers often can perform a heating load calculation. Both of these professionals should use a robust calculation method or software, such as the Air Conditioning Contractors of America Manual J, to size a heating appliance – methods much more accurate than following typical "rules-of-thumb" that were often used in the past. To estimate the heating demand, calculate the heat loss of the buildings being considered by estimating the inslaution level (R-value) of the walls, floor, roof, and windows and the indoor and outdoor temperatures. Heat loss through the building envelope is calculated based on the R-value of each component and the difference in temperature across the envelope. The heat loss from the envelope is equal to the change in temperature divided by the R-value of the envelope (then multiplied by the area). For example, a wall with R-21 fiberglass batt insulation on a day that is 10°F outside with an interior temperature of 70°F will lose 3 BTU/hr of heat energy through each square foot of the wall (not counting windows that usually have an R-value of 3 or 4.) Each component of a building has a different R-value, and structural members, like studs, have a lower R-value than the rest of the wall. The sum of all the heat loss across the varying components of the envelope will give you the conductive heat loss of the home. If the building is leaky with cold air entering through windows and doors, then the convective heat loss needs to be added to all of the conduction losses in order to determine heating demand. The overall heat loss from the building at the coldest outside temperature for your area should be used to determine the size of the heat pump.

Resources

Roth, K., J. Dieckmann, and J. Brodrick. (2009) "Heat pumps for cold climates." *ASHRAE Journal.*

Notes

MONTANA STATE UNIVERSITY EXTENSION
WESTERN SARE Sustainable Agriculture Research & Education
UNIVERSITY OF WYOMING EXTENSION

STEP 5

E3A: Ground Source Heat Pumps

Robbin Garber-Slaght, Vanessa Stevens, Molly Retting, and Art Nash; Milton Geiger editor E3A Program

Proper installation of a GSHP involves numerous considerations, such as system sizing, integration with the distribution system, ground loop installation, and refrigerant work. Hiring a qualified installer is essential and may be required to keep warranties valid. As with any construction project, be sure to obtain more than one bid, remembering that the cheapest option may not be the one with the highest quality installation or most comprehensive warranty. The checklist on the next page will help evaluate available contractors.

Geothermal Systems
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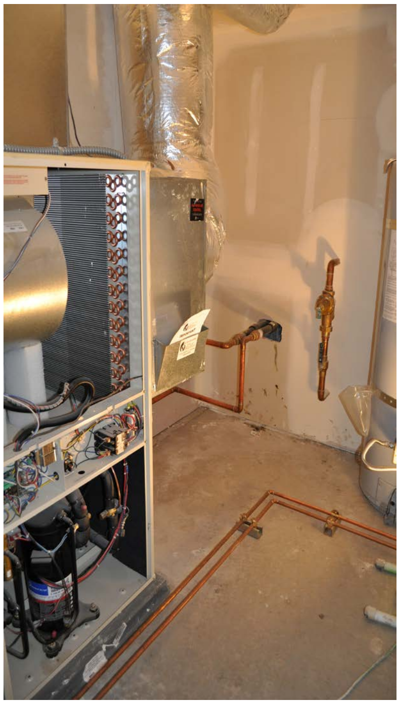

"Water to Air Heat Pump" by Original uploader was Marktj at en.wikipedia.org - Transferred from en.wikipedia; transferred to Commons by User:Teratornis using CommonsHelper.. Licensed under Public Domain via Commons - https://commons.wikimedia.org/wiki/File:Water_to_Air_Heat_Pump.jpg#/media/File:Water_to_Air_Heat_Pump.jpg

Geothermal shilsholepointe
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Table 1: Choosing an installer

Contractor Information		
Name:		
Phone number:		
Bid:		
Referrals and license	**Yes**	**No**
Referred by a friend, coworker, or neighbor?		
Does the contractor have experience installing GSHPs in the site area?		
Was the contractor able to provide names of past customers?		
Check the appropriate state's website to see if mechanical contractors need to be licensed for installation of GSHPs. To check if a contractor is licensed, ask the contractor, or search the state database of licensed contractors. Are they bonded and insured?		
All contractors should carry insurance for liability and workers compensation. Ask the contractor to see a copy of his or her insurance and verify it's up to date.		
GSHP contractors should be certified by the International Ground Source Heat Pump Association (IGSHPA) or by a heat pump manufacturer. This guarantees they have had training in installing GSHPs. Is the chosen contractor certified?		
Building Evaluation and Sizing	**Yes**	**No**
Will the contractor inspect the building and current system to evaluate any needs? This inspection should take at least an hour.		
Does the contractor use the Air Conditioning Contractors of America Manual J or a similar calculation to size the heating system? Algorithms that use characteristics of the building to size the heating system will be more accurate than using a rule-of-thumb estimate.		
When replacing a system, did the contractor ask to see the information about the previous system, such as maintenance records or fuel bills?		
For existing distribution systems, will the contractor test for leaks before AND after improvements are made? Results of both tests should be given to residents.		
Equipment	**Yes**	**No**
Does the contractor install EPA ENERGY STAR-rated GSHPs?		
Will an appliance manual and warranty information for the heat pump be left with the building residents or operator?		
Is the contractor willing to incorporate extra features, such as zoning or a programmable thermostat, and demonstrate how to use them? Note: All features, such as zones, may not apply to all situations.		
Will the contractor demonstrate what maintenance the owner can do and help residents set up a maintenance schedule for professional check-ups?		
Proposal	**Yes**	**No**
Does the written proposal contain a timeline for installation and payment?		
Does the written proposal have itemized estimates?		
Does the contractor know about potential rebates available?		
Will the contractor obtain the proper permits for the system?		

STEP 6

E^{3}A: Ground Source Heat Pumps

Robbin Garber-Slaght, Vanessa Stevens, Molly Retting, and Art Nash; Milton Geiger editor E3A Program

Installation Costs

A GSHP will cost more to install than traditional heating and cooling appliances, such as a boiler, furnace, or air conditioner. The cost of the installation will also depend on the size of the system, as larger systems often require a more expensive appliance and a larger ground loop. As described in step 7, GSHPs are typically sized by the ton, where 1 ton is equivalent to 12,000 BTUs of heating/cooling per hour. Larger heat pumps that need to provide more space conditioning will have a higher number of tons.

The heat pump unit itself costs roughly $2,500 per ton, depending on the manufacturer and model. This price is an investment for the pump alone and does not include the cost of installation or the ground loop. The ground loop can run from $10,000 to $30,000 depending on the type of ground loop and other site requirements. Thus, a 3-ton vertical well system could cost from $17,500 to $37,500 for the unit and ground loop. This rough estimate does not include the heat delivery system to the building. For retrofits, the delivery system will already be in place, and the price should be adjusted appropriately.

Financial Incentives

There are several incentives to help businesses, agricultural producers, and homeowners install a GSHP. The federal government offers a renewable energy tax credit of 30 percent (for residential) and 10 percent (for commercial) for the installation and equipment costs (currently in place until December 31, 2016). Some states also offer incentives. To see if your state offers incentives, visit the online Database of State Incentives for Renewables and Efficiency http://www.dsireusa.org/. Additionally, many electric utilities offer financial incentives to encourage the use of high-efficiency heat pumps.

Energy Economics

To determine if a GSHP will be cost-effective, an understanding of local energy costs, both electricity and heating fuels, is vital. For example, what is the cost per gallon of heating oil? What is your price per delivered gallon of propane? What is the electricity rate per kWh? What about natural gas price per therm? Table 2 aids in tracking this information.

Table 2: Recording fuel costs

Fuel costs in your area:	
Cost of electricity per kWh	
Cost of heating oil per gallon	
Cost of propane per gallon	
Cost of natural gas per therm	

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In heating mode, a GSHP uses electricity to transfer energy from the ground to a higher temperature for delivery to the interior of a building. Consider the local price of electricity and other fuels over time – are prices expected to rise or stay the same? If the cost of electricity is relatively high compared to the cost of heating oil, natural gas, or propane, a GSHP might not be the most cost-effective option.

Each energy source has a certain amount of heating content per unit that can be measured by a BTU. For instance, heating oil is typically 138,000 BTU/gallon, natural gas is typically 100,000 BTU/therm, and electricity is 3,413 BTU/kWh.

Table 3: Converting heating fuels

Heating content of fuels	
1 gallon heating oil	138,000 BTU
1 therm natural gas	100,000 BTUs
1 kWh electricity	3,413 BTUs
1 gallon of propane	90,000 BTUs

Since each source has a different unit of measurement, look at the cost of heat in terms of dollars per 1 million BTUs of useful heat from each fuel. By "useful heat," we mean the amount of heat delivered to a space – this depends on the heating fuel source and the efficiency of the heating appliance in utilizing the given fuel. Fuels with a higher heating content will mean more heat is delivered to a building. Also, appliances with higher efficiencies will mean more useful heat is delivered. Here are a few equations to help equate a variety of energy sources:

Heating oil

Natural gas

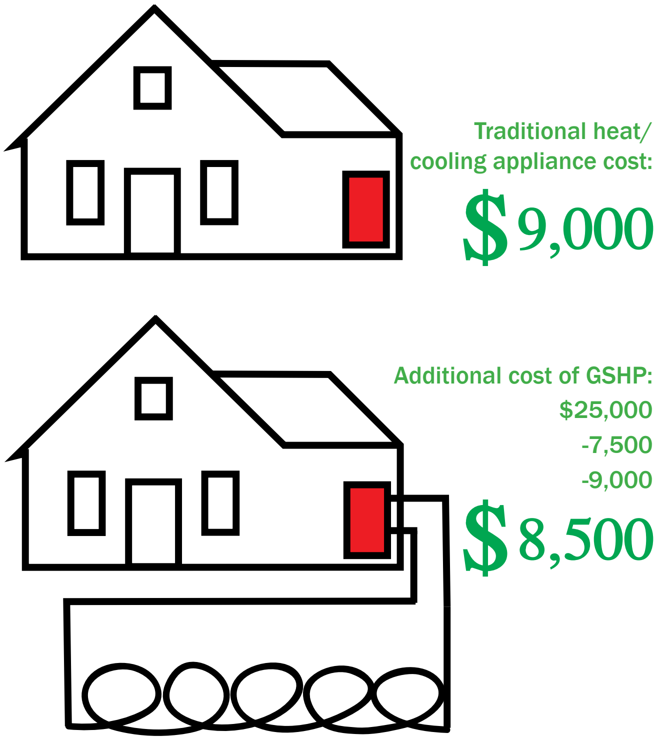
GSHP

Propane

The fixed coefficients (e.g., 7.25, 10.0, 293, and 11.1) are fixed constants that convert the units to BTUs. Simply insert the local price of fuel and the expected efficiency of heating appliances.

Example – Payback Calculation

When thinking about installing a GSHP, consider the simple payback on the installation cost. The simple payback indicates the number of years for the operational savings of the GSHP to equal the additional installation cost compared to the alternative. Other more advanced measures, including return on investment, levelized cost of energy, and net present value, can provide a more accurate evaluation, but the simple payback is easily understood. For example, consider a residential 3-ton heat pump that costs $25,000 for the equipment and ground loop. (This would not include the heat delivery system, but a heat delivery system would cost approximately the same regardless of what heating appliance is chosen). The residential federal tax credit rebates 30 percent of the installed cost of the heat pump. Now let's compare that to a traditional boiler or furnace. An average boiler/furnace with air conditioner will likely cost about $9,000 installed. Since the homeowner would have to spend at least $9,000 to get a heating/cooling appliance, the value can be subtracted from the additional cost of a GSHP. Thus, the additional cost of the GSHP would be:



After federal rebates and deducting a traditional system, the actual additional cost of the GSHP, over that of getting a traditional system, is $8,500. Comparing the operational cost of four heating sources to a GSHP allows for an informed decision on economic viability. Table 4 displays general energy costs for Montana as and above a typical western U.S. example. The table assumes efficient appliances (such as a GSHP with a COP of 3.5 and a furnace/boiler with an AFUE of 85 percent). These calculations show that a GSHP has the least cost per million BTUs ($9.20); however, this cost is not that much less than natural gas ($11.06).

The annual heating cost calculation (middle column in Table 4) addresses the size of a building's heating load. This

Table 4: Example calculations for Montana

Energy Calculations for Montana	Annual heating cost for 53 MMBTU	Annual savings by using a GSHP
Heating oil	$33.26*53=$1,763	$1,763-$487.60=$1,275
Natural Gas	$11.06*53=$586.18	$586.18-$487.60=$100
GSHP	$9.20*53=$487.60	--
Propane	27.03*53=$1,432	$1,432-$487.60=$945

estimate assumes a heating load of 53 million BTUs for the year (for an "average" U.S. 2000 ft2 residence). The GSHP can meet the annual heating load at the lowest cost. The savings is calculated by finding the difference between the operational costs of the GSHP and other fuels (in the third column).

Now, to calculate the payback, examine the operational savings compared to the added installation cost.

Payback to install a GSHP system instead of fuel oil appliance in this example:

Payback to install GSHP instead of natural gas appliance in this example:

Payback to install a GSHP instead of a propane appliance in this example:

In this example, the GSHP pays itself off after seven years when compared with an oil-fired appliance. The return is enhanced if maintenance costs are considered (which can be about $160 a year for oil appliances). If planning to use ranch buildings and a residence for that long, a GSHP might be a good option over fuel oil, especially if electricity prices are predicted to remain stable at $0.115/kWh.

On the other hand, the payback over natural gas is considerably longer – longer than the life of the heating appliance. So in this scenario, a GSHP is not cost-effective to install. There may be other reasons to install a GSHP, such as environmental concerns or the volatility in natural gas prices. Still, the realtively low cost of natural gas makes the GSHP a challenging investment.

Of course, the amount of annual savings depends on several constraints, which are different for each building. Also, the higher the cost of heating fuel alternatives, including natural gas, propane, and heating oil, the more attractive a GSHP will be. To understand yearly operating costs of a GSHP in your area, repeat the calculations and compare the values to other alternative fuels.

Many installers have software that can run comparisons of different heating systems for you, so don't hesitate to ask questions about the payback period of a GSHP.

Resources

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U.S. Department of Energy (2011). Guide to Geothermal Heat Pumps. Retrieved Nov. 24, 2014, from http://energy.gov/sites/prod/files/guide_to_geothermal_heat_pumps.pdf

Alaska Energy Engineering LLC, Ground-source Heat Pump Feasibility Study: Life Cycle Cost Analysis, December 2007 from http://www.juneau.org/airport/projects/documents/GroundSourceHeatPumpFeasibilityStudy.pdf

Geothermal heat pump Photo by Craig Miller Productions, NREL 02400
http://images.nrel.gov/viewphoto.php?imageId=6315656

Notes

STEP 7

E^{3}A: Ground Source Heat Pumps

Robbin Garber-Slaght, Vanessa Stevens, Molly Retting, and Art Nash; Milton Geiger editor E3A Program

Water to Water Heat Pump
Photo by Marktj at English Wikipedia - released into the public domain by its author, Marktj at English Wikipedia. This applies worldwide.
https://commons.wikimedia.org/wiki/File:Water_to_Water_Heat_Pump.jpg

Ground source heat pumps require less operation and maintenance tasks than combustion heating appliances. Additionally, since heat pumps have no on-site combustion or fuel storage, they are safer to operate than combustion appliances. In a sense, a GSHP is similar to a refrigerator – the appliance operates quietly in the background but does require some small tasks to ensure peak operating efficiency.

Both the system owner and the installation contractor are essential for the correct operation and maintenance of a GSHP. The contractor who installs the system should explain needed maintenance and how the owner can ensure the GSHP is operating properly. The contractor can set up a maintenance schedule for self-administered tasks, such as changing the filters for a forced air distribution system or switching controls to change from heating to cooling mode. The contractor can perform periodic tasks, such as a regular check-up of the heat pump components and connections. Next, the appliance manual will list maintenance tasks, operation tips, and will also help troubleshoot if there is a problem.

In general, a heat pump has an estimated lifespan of about 25 years. The ground loop can be used for 50-plus years. The high-density polyethylene pipe used in the typical ground loop installation is durable, and leaks are uncommon; however, a leak in the ground loop will need to be corrected, either by finding and fixing the leak or closing off a portion of the ground loop. The solution to an in-ground leak will depend on the type of system. Additionally, some installers may warrant their ground loops for leaks; this is good information to know when choosing an installer. Refurbishing may be an option at the end of these life spans, yet with advances in monitors, circuitry, and software buying a new unit may be cheaper and more efficient.

Resources

U.S. Department of Energy. (2012). “Geothermal Heat Pumps.” Retrieved Nov.14, 2014, from http://energy.gov/energysaver/articles/geothermal-heat-pumps

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Notes

STEP 8

E3A: Ground Source Heat Pumps

Robbin Garber-Slaght, Vanessa Stevens, Molly Retting, and Art Nash; Milton Geiger editor E3A Program

Direct use hot water surface collection considerations

While expensive analysis and drilling are needed to tap heat (usually in the form of steam) from the earth's deep geothermal wells, there are fortunate areas that have surface reservoirs of hot water. Hot springs are common throughout the western United States and can be tapped as a renewable energy source. When a hot spring is found on property near a building, simply pumping hot liquid to heat registers or a holding tank may be acceptable.

In some cases where the surface water may be bubbling at near boiling temperatures (212 F/100 C), the water may be collected into an insulated pipeline and moved to a hydronic distribution center in a building. If the water source is higher than 50° F, the thermal resource can often be used for purposes other than warming buildings. Commercial hot springs are the most prevalent example, but other opportunities exist. Warm surface water is often diverted and mixed with cooler water for irrigation to grow crops or for use in greenhouses (though direct contact with foodstuffs may require testing for microbes and other organic contaminants). Direct use is also used in foodstuff processing, such as pasteurizing milk. In some ranch locations, such spring surface waters are being used to raise alligators and other exotic species normally found in more hot and humid locations. In fact, several locations in Alaska, not far from the Arctic Circle, such springs are being used for domestic heating. Proximity to the end use is always a lynchpin, as naturally heated water will lose heat quickly in the transportation through pipes and channels.

Direct-use geothermal opportunity (Courtesy of H. McIntrye, Alaska Center for Energy and Power)

Air source heat pumps

In more temperate regions, where the winter temperatures tend to stay above 25° F, the same heating and cooling exchange can be used with air rather than piped fluid circulated in the ground. This is an air-source heat pump (ASHP). As with GSHPs, the relative

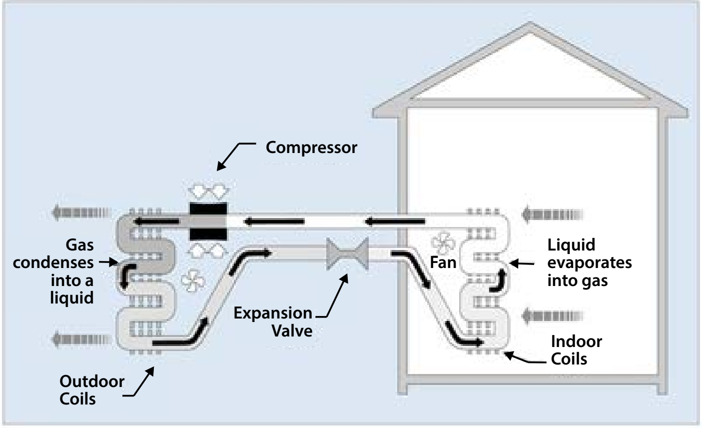

Figure 5: Air source heat pump (Courtesy of Cold Climate Housing Research Center) www.cchrc.org/air-source-heat-pumps-southeast-alaska

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Suggested acknowledgment: Robbin Garber-Slaght, Vanessa Stevens, Molly Retting, and Art Nash; Milton Geiger editor E3A Program: Ground Source Heat Pumps, Fact Sheet 8, How Ground Source Heat Pumps Work. E3A-GSHP.8. 2015.

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Greenhouse heated with geothermal energy
Photo by Geothermal Heat Pump Consortium, NREL 07191. http://images.nrel.gov/viewphoto.php?imageId=6313776

price difference between electricity and the alternative heat fuel is important – ASHPs are most practical where electricity prices are relatively low. ASHPs work by the same principles as GSHPs, but they do not require a ground loop and are thus lower in cost.

ASHPs, as with GSHPs, do not convert electricity into usable heat but rather exchange heat from air (utilizing the transition of liquid to a vapor state inside piping and coils to be condensed back again into a liquid state). The heat brought in from outside can be, as with GSHPs, used to heat air that is blown by a fan(s) through ducts. The heat can also be brought through a ductless heat pump (DHP), which runs through an outside set of coils, then piped into a heat exchanger inside the building. These units often are mounted like an air conditioner, protruding through the outer wall, so the useable heat exits out of the interior portion of the boxed unit and rolls off the wall. There are also ventilation heat recovery systems in which stale indoor air is run through a heat exchanger to surrender its heat to the incoming fresh air. Finally, air to water heat pumps can utilize outdoor or ventilated air to transfer heat to water that then goes to baseboards, in-floor tubing, or storage tank heating. In each case, the heating season performance factor (HSPF) and coefficient of performance (COP) are examined to gauge overall cost effectiveness.

Resources

Stevens V., Craven C., Garber-Slaght R, April 2013 Air Source Heat Pumps in Southeast Alaska, found at: http://www.cchrc.org/sites/default/files/docs/ASHP_final_0.pdf

Notes